What makes an undergraduate course impactful? An examination of students' perceptions of instructional environments

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Abstract

To provide significant learning experiences for undergraduate engineering students, educators have resources in the literature, colleagues, and personal experiences to supplement their course design process. This study aims to capture the stories of graduate students who are looking back at their undergraduate experiences and describing the features that made a specific course particularly impactful. Specifically, the goal of this study was to explore the educational philosophies enacted in the most impactful undergraduate classrooms, according to graduate students' perceptions, for the purpose of designing effective instructional environments. To capture the characteristics of the impactful courses, graduate engineering students from the Georgia Institute of Technology participated in an online survey. Participants reflected on the instructional environment that best described their most impactful undergraduate learning experience. Open-ended questions provided students with the opportunity to further justify or clarify their responses. The analysis indicated that students' most impactful classes were required, in-major, non-design courses. Furthermore, these courses were characteristic of instructor-centered philosophies, including essentialism and perennialism. However, when students did reflect on out-of-major courses, they tended to recount a wider variety of enacted philosophies, including more learner-centered ones (progressivism, social reconstructionism, and existentialism). Qualitative analysis of students' descriptions of their most impactful classes revealed five major factors that contribute to the success of a course: course components, the instructor, the student experience, the subject matter, and other stakeholders (e.g., peers and teaching assistants). Exploring these impactful classroom experiences highlights connections between the literature and student experiences as well as supports new faculty who are considering the type of instructional environments they will strive to create in their own courses.

Keywords: instructional environments, educational philosophies, impactful courses, undergraduate engineering education

Introduction

Much educational research has focused on studying the efficacy of innovative teaching strategies for enhancing student learning. Many authors have cited that pedagogies founded on learner-centered teaching philosophies, such as problem-based learning, collaborative learning, and experiential learning, have many benefits over more traditional, instructor-centered tactics, such as lecturing. For example, participation in non-traditional learning environments has been shown to increase student motivation[1] and sharpen practical problem-solving skills[2,3]. Conversely, other researchers have demonstrated that students often perceive direct instruction to be more effective than learner-centered practices[4]. With this in mind, new faculty in particular should be concerned about these student perceptions and preferences – they will drive important factors such as motivation and willingness to work hard for an unknown professor[5,6].

One of the first (and daunting) tasks of a new educator is the planning of a course. It is tempting to sit down and create one's syllabus in a linear manner, only considering the content at hand and the calendar of the term. However, to have a truly successful course, the educator should approach this task as a design task – one is designing not only the sequence of events for the next 2-3 months, but in fact, one is designing the actual environment for those events. Approached in this manner, the engineering educator has an advantage over many other fields – engineers are well accustomed to the work of design.

There are many things to consider when designing one's instructional environment. Clearly, one will consider what environmental factors will lead to be most effective student learning (for more on designing courses in general, see L. Dee Fink's work)[7]. Given the research such as that cited above, it is clear that there is a need for the New Engineering Educator to consider both the theoretical benefits related to student learning alongside actual student perceptions of the teaching and learning process. The goal of this project is to explore the educational philosophies enacted in the most impactful undergraduate classrooms, according to graduate students' perceptions, in order to give the new educator a foundation for their own course design process.

Previous Research

Why Examine Students' Perceptions of Learning Environments?
At the start of the new semester, students enter a classroom not as "blank slates," but with particular conceptions about teaching and learning based on their prior experiences[5]. As a result, the effects of learning activities and perceptions of classroom interactions among the instructor and the students may differ by student[5,8]. Further, research has also shown that students' conceptions about teaching and learning and their perceptions of the learning environment impact their approaches to studying and thus, their overall learning outcomes within a course[6,9,10].

Take the case of faculty and students at a law school as described by Hativa[6]. The faculty wanted their students to develop critical thinking skills and advance their ability to self-study. Yet, over the course of the semester, faculty grew frustrated as students were regularly absent from class, did not complete pre-class assignments and procrastinated studying until the end of the term. In addition, the students did not appear to want to engage in class discussions. The students, on the other hand, did not perceive that the instructors cared or supported them and their needs. The teaching approach of the faculty was described as ineffective; thus, students did not view attending class as a valuable use of their time. The gap between faculty and students' perceptions of the course created a strong tension between the groups, affecting the experiences of both parties.

The previous discussion is an extreme example of the gap that can be created between faculty and students' perceptions of a learning environment. By exploring research related to factors that negatively impact student perceptions of the classroom environment, educators can seek to

prevent development of such gaps. Studies have shown, for example, that students may develop negative perceptions towards a particular teaching approach simply because they haven't encountered it before[11]. Thus, even evidence-based teaching practices or instructional tools (e.g., clickers, online video lectures, etc.) can be misunderstood or misused by students who are unfamiliar with the practices or the technology[8,11,12]. An instructor's teaching strategy can also create tension in the classroom, particularly if the strategy is not aligned with the students' learning strategies[9,13].

On the other hand, students' perceptions of a learning environment can be considered as an information source or a mediator between the learning environment and lesson-particular learning outcomes[8,14,15,16]. In other words, these perceptions can be used to help educators design the structure and assessments for a course and select appropriate instructional approaches for different learning activities[6]. The student presented in this paper aims to share one set of graduate engineering students' perceptions of impactful undergraduate learning experiences with new engineering educators.

Capturing Students' Perceptions of the Instructional Environments

Explorations of individual student perceptions and interpretations have become more common as researchers have shifted their focus away from observational approaches to examining a classroom climate. Ames[5] explains that: "To predict and examine motivated cognitions, affect, and behavior of a student, it is necessary to attend to how the student perceives and gives meaning to classroom experiences" (pg. 267). As such, researchers have used a variety of methods to understand students' perceptions of an effective learning environment, including student course evaluations[9], semi-structured interviews[9,15], and surveys[9,15,17,18,19]. The scope of the studies also varies from broader examinations of students' conceptions of teaching and learning[9] to specific evaluations of students' satisfaction with pedagogical techniques or classroom activities[17,20].

Results of these studies highlight several key components of students' perceptions about instructional environments. In a 1994 study[19], students described an effective instructional environment as one where the teachers transmit the information and the students are "passive recipients of well-structured and presented material" (p. 9). These findings were consistent with other studies around the same time that identified students' preference for clear, interesting, and well-prepared instructors[9]. In a 2000 study of engineering students, the preferred instructional environment included instructors who organize and structure their presentation effectively or instructors who promote a supportive learning climate and guide effective studying[9]. The second type of instruction aligns with the law school example and a more recent study of senior engineering students who perceive that faculty commitment to student success is important for their learning and success[6,18].

Overall, these studies suggest that many students prefer instructional environments that are at the intersection of learner- and instructor-centered, rather than at either extreme[9]. According to Hativa and Birenbaum[9] these findings indicate that students, "on average, seem to dislike putting

too much thinking effort and independent work into their learning" (p. 227). On the other hand, research by Lowyck and colleagues[15] on students' perceptions of high quality instructional environments reveals students' preference for a "diversified" and "well-balanced" environment (p. 435) and one that challenges the learner.

The studies discussed above represent the perceptions of students ten to fifteen years ago and many include a mix of engineering and non-engineering students. As we begin to consider the perceptions of students entering our courses, it is important to recognize that our students may arrive on our campuses expecting different things than students did a decade ago. Thus, in the study presented in this paper, we explored the perceptions of alumni to first, gather information from a more current sample, and second, to capture the perceptions of a group not commonly discussed in the literature. Thus, the focus of our study was graduate engineering students who reflected back on the instructional environments from the undergraduate years to provide educators with a clearer understanding of the environments that have positively impacted their lifelong learning.

Classifying Learning Environments

Research suggests that underlying many decisions made by educators are their knowledge, beliefs and perceptions about the learning environment[6,16,21,22]. These conceptions illustrate the "understanding, thinking and beliefs about teaching and learning that can potentially influence teaching actions"[23]. These different beliefs are commonly classified along a continuum from instructor-centered to learner-centered[22,23]. At one end of the continuum, the instructor is considered the central figure in the learning environment and his or her role is to dictate, or transmit, course material to students. At the other end, the most learner-centered viewpoints focus on students as the agents of their own learning while their instructors serve as facilitators in the learning environment. The literature includes many different classifications for conceptions along this continuum[22,23,24,25,26]. In this study, the authors utilize five contemporary philosophies of education to classify learning environments[22,25]. Two are instructor-centered, while the other three are learner-centered philosophies (See Table 1).

Table 1. Comparison of philosophies of education, including differences in focus of study and instructor role (Adapted from Koch[27] used in a previous work by the authors[28]).

Philosophy	Focus of Study	Role of Instructor
Perennialism (Instructor-Centered)	Enduring ideas found in the great works of the field.	Instructors dialogue with students to reason about the great ideas.
Essentialism (Instructor-Centered)	Core knowledge that students need to be educated citizens; this knowledge is embodied in traditional disciplines.	Instructors are the central figures in the classroom, transferring their knowledge to students.
Progressivism (Learner-Centered)	Integration of study with real-life experiences through active learning, problem solving, and experimentation.	Instructors structure the learning activities and encourage students to explore the ideas that arise.
Social Reconstructionism (Learner-Centered)	Schooling promotes social and political reform by focusing on social problems and the need for change.	Instructors guide students to think critically about social injustice and challenge oppression.
Existentialism (Learner-Centered)	Students choose their own course of study in an effort to figure out their place in the world.	Instructors support students in exploring their own interests.

The viewpoint of the learning environment for the two instructor-centered philosophies, perennialism and essentialism, is that the content and skills are transmitted from instructors to students. In a learning environment that reflects perennialism, the instructors serve as central figures, guiding discussion of timeless knowledge from seminal works in the field. Essentialism, on the other hand, illustrates an environment where fundamental concepts from the discipline are transmitted from the instructor to the student through, most often, a lecture style format. The three learner-centered philosophies, progressivism, social reconstructionism, and existentialism, describe environments that focus more explicitly on learners' needs and interests. In a progressivist learning environment, students participate in learning activities, and many times, authentic learning experiences, designed or coordinated by the instructor. Social reconstructivists create learning environments centered around students critically examining modern social dilemmas, while existentialists guide the students as they design their own individualized educational journeys. Overall, each of these major philosophies of education can support our exploration of diverse learning environments by providing a framework grounded in the literature[22,23,27].

Methods

Survey Development

The Instructional Environment Survey was developed to capture graduate students' philosophies of education, as well as previous experiences that may have impacted their choice of philosophy. The instrument was developed based on the theoretically-grounded Philosophy of Education

Survey[22] and modified to be applicable to higher education. Specifically, the new instrument asks students to provide information on demographics, the types of formal and informal teaching and learning instruction they have received, and their future teaching goals. Afterward, students are provided with descriptions of five model instructional environments that are characteristic of each of the five major educational philosophies: essentialism, perennialism, progressivism, social reconstructionism, and existentialism (Table 2). Students were asked to reflect on their most impactful courses from their undergraduate and graduate careers, as well as their own future classrooms, and rate (on a five-point scale) how similar these classroom environments were or will be to the model descriptions. Only respondents' reflections on their most impactful undergraduate course were analyzed to answer the current research questions in this paper.

The Instructional Environment Survey was reviewed by a number of parties to ensure validity, as suggested by previous authors[28,29]. First, a draft was evaluated by a group of professionals who work in the area of graduate education. Feedback was incorporated into the instrument and the revised version was piloted with a group of recent engineering Master's and Ph.D. graduates. Feedback from the graduates was used to clarify and improve the instrument. The final version of the survey is available in Appendix A.

Table 2. Descriptions of classroom environments that are characteristic of the five major educational philosophies.

Educational Philosophy	Instructional Environment
Essentialism	Students learn the existing core of common knowledge in a discipline. Instructors are central figures in the classroom who transfer core knowledge to students in a methodical manner, usually addressing basic concepts before tackling more advanced topics.
Perennialism	Students are encouraged to question facts as they uncover fundamental, unchanging principles and sharpen their analytical skills. Instructors serve as central figures who guide discussions to help students uncover these principles. For instance, emphasis is placed not only on how to manipulate an equation, but also on the reasoning behind the development of the equation.
Progressivism	Students participate in hands-on learning as they grapple with real-world questions and problems. Instructors structure learning activities to cultivate student exploration and mold students into life-long learners who can be successful in an ever-changing society.
Social Reconstructionism	Students learn subject matter as part of thematic units focused on grand social challenges, such as improving access to clean water, developing alternative energy sources, etc. Students and instructors work together to select social themes and decide on learning objectives.
Existentialism	Although guided by the instructor, students decide what they learn. Every student is different, so no one set of learning objectives is appropriate for an entire class. The instructor is a facilitator who assists in defining appropriate topics and serves as one of many resources in the learning process.

Survey Dissemination

The Instructional Environment Survey was disseminated to engineering graduate students enrolled at the Georgia Institute of Technology, a large, technical, research-intensive university. Students from all engineering departments were invited to participate (aerospace, biomedical, chemical and biomolecular, civil and environmental, electrical and computer, industrial and systems, materials, mechanical). The survey was distributed via Survey Monkey.

Overall, 88 graduate students completed the survey item asking them to reflect on the educational philosophies enacted in their most impactful undergraduate courses. The majority of respondents were males (59.1%) from the United States (US) (68%) who attended research universities as undergraduates (Table 3). Mechanical and electrical/computer engineers were highly represented in the sample (Table 4).

Table 3. Carnegie classification of undergraduate institution.

Basic Carnegie Classification	Percent (%)
Research University (Very High)	55.7
International	18.2
Research University (High)	15.9
Bachelorette Colleges (Arts and Sciences)	6.8
Research University	1.1
Masters (Large)	1.1
Masters (Medium)	1.1

Table 4. Undergraduate majors of respondents.

Major	Percent (%)
Electrical/Computer	27.3
Mechanical	19.3
Chemical Engineering	9.1
Biological/Biomedical	8.0
Aerospace	8.0
Engineering (Unspecified)	6.8
Industrial	5.7
Civil/Environmental	5.7
Non-Engineering	5.7
Engineering Science	2.3
Materials	2.3

Survey Analysis

Several statistical methods were used to analyze survey data. Upon investigation, the data was found to exhibit a non-normal distribution with homogenous variances. Consequently, the non-parametric Kruskal-Wallis one-way analysis of variance was used to investigate variations in survey responses. Differences in the educational philosophies enacted in students' most impactful undergraduate courses were examined based on a variety of independent factors, including gender, nationality, major, and Carnegie classification of undergraduate institution.

The impact of the type of class cited as being influential, including whether or not it was in the student's major department, required for degree completion, or design-related, on enacted philosophy was also analyzed. Finally, differences in educational philosophies characteristic of impactful courses were also considered based on themes provided in qualitative responses. Significant relationships were identified for $p \leq 0.05$.

Students' responses to the open-ended question, "What about this course made it so impactful?" were analyzed using open-coding methods[30,31]. Specifically, two researchers independently read all of the responses and categorized each response based on the aspects that the participants identified as impactful. Each response was identified with anywhere between 1 and 10 categories. Following the initial read, one researcher integrated the categories. Reading, and rereading, each response and the associated categories, the researcher modified the categories by collapsing them or expanding them. Finally, the two researchers discussed any differences in categorizations until consensus was reached. The result was the emergence of five major components of instructional environments across the responses in the sample that reflected on the reasons the participants viewed a course as impactful. These five categories are discussed in detail in the subsequent section, alongside quotes that are used to illustrate the major themes within the data. It is important to note that the quotes could be classified under more than one category or sub-category. For example, Lewis (all names used in this paper are pseudonyms) explained the reason why Fluid Mechanics was impactful was, "a combination of the style of teaching, the subject matter, and the care that the instructor exhibited for the students." This response describes impact due in part to the instructor and the subject matter. Therefore, our analysis placed this statement under multiple categories to most accurately illustrate what the participant discussed.

Results

Overview of Philosophies Enacted in Undergraduate Courses

When graduate students reflected on their most impactful undergraduate courses, they indicated that the educational environments were instructor-centered (Table 5). In fact, nearly 50% of courses were very characteristic of an essentialist philosophy where the instructor directly disseminates content to students. Moreover, the second most common philosophy was perennialism, where the instructors serve as central figures that guide classroom discussions. Of learner-centered pedagogies, progressivism was most enacted in impactful undergraduate courses.

Table 5. Philosophical influences for most impactful undergraduate courses.

	Median	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Essentialism	4	3.4	6.8	15.9	25.0	48.9
Perennialism	4	6.8	8.0	12.5	37.5	35.2
Progressivism	3	12.5	15.9	26.1	22.7	22.7
Existentialism	2	42.0	22.7	14.8	10.2	10.2
Social Reconstructionism	1	51.1	11.4	14.8	12.5	10.2

Impact of Demographics on Reflections of Undergraduate Courses

The effects of gender, nationality, major, and type of undergraduate institution on students' perceptions of successful undergraduate courses were investigated. The impactful courses cited by international students were more characteristic of social reconstructionism than those described by US students ($p \leq 0.05$) (Table 6). When examining responses by type of undergraduate institution, it was found that courses described by students from baccalaureate institutions were more characteristic of progressivism than those discussed by students from research or international institutions ($p \leq 0.05$) (Table 3). Analyzing data based on gender or major revealed no statistically significant relationships.

Table 6. Philosophies reflected in most impactful undergraduate course by respondent citizenship.

Philosophy	United States (n = 68)			International (n = 20)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(1)$	p
Perennialism	4	14.8	72.1	4	15.0	75.0	0.611	0.484
Social Recon	1	67.6	19.1	3	35.0	35.0	5.742	0.017*
Existentialism	2	67.6	19.1	2	55.0	25.0	0.734	0.392
Progressivism	3	30.8	75.0	3	20.0	50.0	0.453	0.501
Essentialism	5	10.3	73.5	4	10.1	75.0	0.782	0.372

Table 7. Philosophies reflected in most impactful undergraduate course by modified Carnegie classification.

Philosophies	Research Universities (VH, H, DRU, Masters) (n = 66)			Bac/A&S (n = 6)			International (n = 16)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(2)$	p
Perennialism	4.0	13.7	74.2	5.0	16.7	83.4	4.0	18.8	62.5	1.816	0.403
Social Recon	1.0	68.2	21.5	3.0	33.0	33.4	2.5	50.1	25.0	3.544	0.170
Existentialism	2.0	68.1	19.7	3.0	33.4	33.3	2.0	62.6	18.7	2.759	0.252
Progressivism	3.0	30.3	43.9	5.0	0.0	83.4	3.0	31.3	37.6	5.978	0.050*,[1]
Essentialism	5.0	9.1	74.2	5.0	0.0	100.0	4.0	18.8	64.6	3.755	0.153

[1] Dunn post-hoc: International – Bac/A&S: p = 0.021*; RU – Bac/A&S: p = 0.019*

Relationship between Type of Course and Enacted Philosophy

Numerous types of classes were cited by students as being especially impactful. Overall, most courses were required, within students' major, and not design-related (Table 8). Interestingly, non-required courses tended to have more diverse educational environments, as they more significantly integrated elements of perennialism, social reconstructionism, and existentialism than required courses. No statistical differences were found based on whether or not the course was within a student's major or design-related.

Table 8. Types of undergraduate courses cited as being impactful.

	Required	In Major	Design Related
Yes	83.2	80.7	6.8
No	11.4	14.8	92.0
Unknown	3.4	4.5	1.1

Table 9. Differences in educational philosophies enacted in impactful required versus non-required courses.

Philosophy	Required (n = 75)			Not Required (n = 10)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(1)$	p
Perennialism	4.0	17.3	70.7	5.0	0.0	100.0	6.394	0.011*
Social Recon	1.0	62.4	23.5	4.0	40.0	60.0	5.066	0.024*
Existentialism	2.0	70.7	14.4	4.0	30.0	60.0	9.494	0.002**
Progressivism	3.0	32.0	41.3	4.0	10.0	70.0	2.833	0.092
Essentialism	5.0	8.0	78.6	4.0	10.0	60.0	2.018	0.155

Students' Definitions for Impactful Instructional Environments

Seventy-four participants provided written responses discussing their experience within their most impactful course. As previously mentioned, five characteristics of instructional environments emerged from the qualitative analysis as common among the students' descriptions: the instructor, the subject matter, the course components, the student experience, and other stakeholders (e.g., teaching assistants, peers). The most commonly discussed aspect of the instructional environment, as seen in Table 10, was related to the design of the course (i.e., course components). Course components for this analysis describe the learning activities, assessments, and structure of the impactful course. The instructor and student experience were identified by 40% of the sample (n = 30) as contributing to the course being impactful. The student experience category captures discussions of participants' individual development during the particular course. For example, Ann explained that the Signals and Systems course she took "introduced [her] to the topic area that [she] decided to pursue after graduation." The subject matter category, which includes remarks by one-third of the sample, describes remarks about the specific material or content of the course. Chris, for instance, discussed how, "the material [in his real analysis course] helped [him] immensely in furthering [his] understanding of complex mathematical topics." Finally, six participants noted instances where the actions of the teaching assistants and the interactions with the peers made their experience in the course impactful. The

following sub-sections will further detail the participants' reflections on their most impactful undergraduate course.

Table 10: Number of students who described particular components of the instructional environment as impactful [NOTE: Students' responses could be classified under multiple categories].

Category	Frequency	% of Sample
Course Components	49	66.2
Instructor	30	40.5
Student Experience	30	40.5
Subject Matter	25	33.8
Others (e.g., TA, peers)	6	8.1

Course Components

When designing a course, one of the important aspects that we, as educators, consider are the variety of potential learning activities and structures for delivering and assessing the course content. Forty percent of the remarks included some discussion of particular in-class activities and assessments, including, but not limited to in-class demonstrations, projects, presentations, labs, competitions, and example problems.

Grace's Mechanics of Materials course, for instance,

> "had a laboratory component, where [she] explored phenomena discussed in class in the physical world - this helped [her] link equations and concepts learned in lectures to how materials physically deform."

Victor, on the other hand, was impacted by the problem-based learning experience he had in System Dynamics & Control:

> "I believe that I devoted the most time towards this one particular class during that semester, but also got the most out of it. My research, programming, and presentation skills were sharpened like never before, and I learned to appreciate the value of resourcefulness, initiative, and constructive feedback."

Almost another forty percent of the comments (n = 18) related to the inclusion of "the real world" into the course, whether through connections between content and real world challenges or interactions with clients on projects. Silvia traveled to India, for example, as part of her Humanitarian and Social Entrepreneurship course. "We had to create everything from zero in a true startup environment. It was incredibly frustrating but taught me a lot." Xavier appreciated how Spacecraft Design II,

> “was [his] first real taste of what it's like to be an engineer in spacecraft systems. [He doesn’t] think [he] realized it at the time, but [he] learned a lot of valuable things about working on a team and what is really important in design.”

Ten participants described the challenging nature of the course as what made it impactful. For some, like Turner, Fluid Dynamics was challenging, but doable:

> “It was very difficult, but not so much that I couldn't do it, and it was fun to think about. I think most of all it was hard, and so very satisfying when I got it.”

For others, like Robin, the Environmental Engineering Design course was challenging, but rewarding:

> “Each student was required to design a nanofiltration plant for drinking water, using real source water quality data. I enjoy self-study because it forces me to learn every aspect of a project, immersing me into a subject. The design of the nanofiltration plant was very challenging and required a lot of work but I think this is why it was so impactful. Not only was I able to apply what I had learned to tackle a real engineering challenge but all the hard work I put into it made sure I got something good from it. Overall, I think the reason the course was so impactful was because the challenge motivated me to work hard.”

Nine participants characterized the course as designed with an explicit focus on learning. Zach described his experience in a student-driven Concrete Discrete Mathematics class:

> “The course was offered by an instructor who wanted to delve into a math text. In order to force himself to move through the content, he offered it as an elective course for advanced undergraduates and graduate students. Students went through the text individually and presented what they learned. Homework problems were selected by the students and they would present their solutions for the class. Much of the learning was led by the class itself; the instructor provided the necessary framework (e.g., expectations and grading criteria), but he made himself a part of the class by demonstrating solutions and topics in the same way as the students.”

For Wendy, it was the design of an elective course that she took on Genesis that was impactful:

> “[the instructor’s] motto is "One good reading of one good passage." His classes focus in the deep, intensive understanding of fundamental texts of early Christianity. We consistently tied these texts to current day themes and explored how interpretations and understanding can change through time. For [the instructor’s] classes, understanding was focused on quality, not quantity. In the end, I gained more skills and applicable understanding that way than I could have gained from a fire-hose approach covering 10 fundamental texts.”

Marissa, one of six participants who cited their most impactful course as having a strong link between theory and practice, explained:

> "[Vehicle Dynamics] encompassed simulation, and test trials. One took information off a tech sheet and inputted into a simulation. It was then compared to the experimental run (there was a sports car with sensors attached). Not only learning about the different types of suspension (e.g. McPherson strut, independent, leaf spring, ...) but seeing them in actual life in a car."

Andrew described his experience moving from theory to application in Electromechanical Energy Conversion Laboratory:

> "The major impact came from the fact that using the theory and some equipment, my colleagues and I were able to transform energy in a predictable and controlled manner. Also, we had the opportunity to identify what the theory was missing while representing physical phenomena. Overall, it presented me a glimpse of the difficulties that one must face in order to take theory into applications."

Finally, a few participants also described the interactive learning environment, the focus on teams, as well as the time intensive nature of the course in their reasons why the course was impactful.

Instructor

The literature provides two higher-order dimensions – cognitive and affective – to classify teaching behaviors that are characteristic of effective teaching[32]. The participants' responses were originally categorized into 25 sub-categories of instructor-related comments with categories representing from 1 to 6 comments. Of these 25 sub-categories, 12 describe behaviors that can be classified as part of the cognitive higher-order dimensions and 11 can be classified as part of the affective higher-order dimension. The other two were general sub-categories – effective instructors and teaching style - to describe participants' responses that were positive, but too general to understand the basis for the comment.

The cognitive higher-order dimension sub-categories describe the pedagogical-instruction skills, intellectual stimulation, communication of material, and delivery aspects of teaching, or as Hativa[32] describes it the "communication of the material" dimension (p. 12). Of the 48 references to instructors, almost 50% related to the instructor's ability to communicate the material. For participants like Carol, it was the delivery of the material that made the content interesting and the course, in her case Introduction to Fluid Mechanics, impactful:

> "Very enthusiastic instructor, who brought the material to life and made it more interesting through characters ("Mr. Blob"), adding interesting/odd side notes, and in-class demonstrations, while still effectively teaching the core material."

Brian, on the other hand, appreciated the clear expectations and the detailed nature of his Biochemistry II instructor's notes:

> "Was taught by an experienced professor who gave extremely detailed, yet easy to follow, notes during class, and had very clear expectations of what we were supposed to learn by different points in the semester."

In Dynamics, David was impacted by the teaching approach of his instructor and how the material was communicated:

> "The instructor had a wonderful teaching method that both engaged the student, ensured retention of the material, and covered a large volume of material throughout the course."

One-third of the discussions focused on the interpersonal rapport of the instructor, and thus, were identified as part of the affective higher-order dimension. This dimension describes the instructor's interest in the students and their learning, along with how the instructor motivated the students and interacted with them[32]. Frank, for example, viewed his Introduction to Computer Engineering instructor as a role model. "The professors actually listening to me and my issues and giving a solution that could actually be used."

Emily viewed her System Dynamics and Control instructor as supportive and a mentor:

> "Until this course, I tended to sit in the back of the class and did not try to engage with the professor or the material. However, since the professor required us to use name tents and called on us by name I was required to engage with the course. Also, the professor would often check-in with me in the hallway or outside of class. These small moments really helped me overcome the fear and apprehension I had about approaching a professor if I had problems or didn't understand the content. He was very patient and never made me feel dumb. Also, this is the first time a collegiate faculty member singled me out as an "intelligent" student and encouraged me to consider graduate school. He asked me to work with him on a few small undergraduate research tasks and gave me many learning/research opportunities outside of class that helped to cultivate my love for learning."

It was clear that for many participants, the interactions between instructor and student had a positive impact on their undergraduate experience. In Harrison's case, it was in a Signals and Systems course:

> "Very engaged teacher, willing to devote a substantial amount of time to individual or group discussion on the subject matter outside of designated office or class hours. Although difficult, the professor was explicitly clear on what was necessary to succeed in the course and what his expectations were on homework, quizzes, and exams. Furthermore, the professor never altered the course syllabus or curriculum without first

> discussing with the class and explaining his reasoning and intentions. Overall, the professor made the class his primary priority in his academic responsibilities."

For Jacob, it was the time his instructor took to meet one-on-one with the students in the Anthropology of Controlling Processes class**:**

> "The instructor made a point of meeting with each student (of a class of multiple hundred students) at least once, individually, to thoroughly discuss their thoughts on the topic they would be researching and writing about."

Student Experience

For many participants, it was not just the content of the course or the instructor that had a positive impact on their undergraduate career – it was the effect of the course on their overall collegiate experience. For ten respondents particularly, their experiences directly impacted their career pathways. Brena described how Probability and Statistics for Electrical Engineering, "made [her] realize what [she] wanted to do in graduate school." Fiona's experience in Bioelectricity with the topic and the instructor impacted her career path:

> "I just loved the topic. It inspired the field I wanted to go into. The instructor was an incredible instructor for technical content. She was also an excellent resource for moving forward in your career (helped me to get into graduate school afterwards)."

Ernie's career pathway, on the other hand, was inspired by his Fluid Mechanics' instructor's teaching style:

> "This course had the greatest impact on be mainly because of the instructor. I decided to come to graduate school, and to pursue a career in academia, right after taking this class. The professors teaching style was so engaging that it made me want to learn more about the topics covered in class. Even though I am not specializing in the specific area of that class (fluid mechanics and water resources), this class introduced me to the notion of wanting to learn more than what is covered in textbooks."

Eight participants indicated the course's impact on their own self-efficacy. Olivia remembers her Introduction to Electrical Engineering course because of its impact on her mindset going forward:

> "This course was impactful to me because it was my 1st encounter with struggling to pass a class and to understand the material. The learning curve for me was huge. I considered changing my major after this class, but it was impactful because after this class is when I made up my mind that I will work hard to achieve anything that I want to achieve. I will not let difficulty define my decisions, I will take advantage of all resources I need to succeed."

Debra's experience in Creative Decisions and Design helped her build confidence in her engineering skills:

> "Throughout the semester, you give presentations and write reports on different, smaller engineering projects that they assign. My team ended up winning the competition. The entire experience gave me a lot more confidence as an undergrad in my engineering skills. I think this extra confidence boost (in design and in giving presentations) helped me start looking for research in the field I was interested in (acoustics) and ultimately to pursue a PhD."

Ten participants also noted the course's impact on the development of their skills in a particular area, from presentation skills to programming skills. For example, in Greg's case, it was during his Jet and Rocket Propulsion course when he really improved his problem-solving skills:

> "Within this course, I learned a lot about effective structuring of problem solving methods. By explicitly outlining my Givens, Assumptions, what I am trying to Find, the Method/Analysis for finding my answer, and most importantly the Implications of the results, I gained an understanding of both the how and why related to the problem."

Harriet learned skills in her Experimental Measurements and Procedures course that would help her during graduate school:

> "I learned a lot of necessary skills for my later PhD. Got a good introduction to what it means to do research. Good experience tackling real problems like what happens when your experiment doesn't work, or how you explain something that doesn't make sense."

For Clayton, his Introduction to Engineering course helped him build many different skills needed to become an engineer.

> "Students were given personality tests and grouped with non-like-minded team members. The benefits of having input from differing perspectives in the design process was emphasized. Students were challenged with real-world design problems while being encouraged to be mindful of a broad range of design impacts (societal impacts, global impacts, etc.)."

A few others described the impact of the course as exposing them to new fields, different perspectives, and research.

Subject Matter

Twenty-five participants identified aspects of the course content as at least one of the reasons it was the most impactful course from their undergraduate experience. Over half of those participants (64%, $n = 16$) noted that it was specific content within the course that made it impactful. For instance, Nicholas explained his interest in Digital Logic Design, "My interest in the subject is the reason that this course was impactful." Others, like Ryan, described their most impactful course, in his case, Operations Research, as "just a fascinating subject, in my opinion."

Four participants mentioned the foundational nature of the subject matter. Lawrence cited one of his introductory major courses, Introduction to Signal Processing, as impactful:

> "It laid the foundations for signals and linear system theory, Fourier transforms, and much of the basic concepts we continued to revisit in other courses. Concepts laid out in that class were expounded upon in 5-6 other classes, so I think of it as the base of what I learned in ECE."

Kelly and Paul, on the other hand, viewed their mathematics courses as foundational and impactful in their engineering curriculum. Kelly explained that,

> "The math classes had the most impact on me because it really shaped the way I approach any type of problem. It emphasized rigor and soundness of reasoning. It was also the foundation for any engineering class I took afterwards. To this day, I can still remember demonstrations and links between different theories. I guess this is mostly because it is one of the few times when I spent so much time diving into the same topic."

Paul viewed Calculus I as both useful and foundational to his academic pathway:

> "The course is the [basis] of all engineering classes. Besides the knowledge and methodology that I am still frequently using today, I also learned a lot about philosophy of mathematics: a rigorous language describing the word. It is rigorous because you are a "judge": you need evidence for your every step."

Irene, along with another participant, also noted the usefulness of the subject matter as the reason the course was impactful. For Irene, it was Thermodynamics that

> "... helped connect many concepts evident in other courses that had not previously been brought together. It was interesting and challenging which made it rewarding. It showcased engineering principals I observe outside of the classroom. I still use this material in my graduate work."

Teaching Assistants and Peers

A handful of participants shared experiences that were impactful due to their teaching assistants and peers. For Emily, the interactions among her peers turned into friendships that lasted many years after the System Dynamics and Controls course:

> "Another really important aspect of this course was the interaction and collaboration with my peers. Since the content was so difficult, many of us would work on the homeworks together, and I ended up tutoring many of my classmates on the material. The night before an exam, my classmates asked me to hold an informal review session. This was my first teaching opportunity, and I LOVED it. Since I was working with peers, and not

"students," we treated the review sessions as an interactive and collaborative learning opportunity. This also helped to build my network of classmates, and a small group of us continued to take classes together and work together. Eventually, 3 of us were even on the same self-selected senior design team. I still stay in contact with these friends, and we try to continually support each other's careers and personal lives."

Grace appreciated the help she received from her Mechanics of Materials recitation instructor "'translated' complex concepts the professor introduced in lectures in a more understandable way." Jacob echoed the impact that the course staff, in this case, the teaching assistants had on his experience in Anthropology of Controlling Processes:

> "The TA's were very engaging and interested in the students' understanding and success, and they often offered deeper insights into any questions brought up, including offering opportunities for further reading."

Relationship between Impactful Component and Enacted Philosophy

To validate survey responses, students' quantitative assessment of their most impactful course was compared with their qualitative descriptions of their courses. Specifically, differences in enacted philosophies were investigated based on whether or not students cited the role(s) of the instructor, subject matter, course design, student experience, and/or stakeholders.

The role of the instructor had a notable impact on students' classifications of their impactful classrooms as either instructor- or learner-centered. As expected, the median scores for instructor-centered philosophies tended to be higher (Med = 4.5 – 5.0) than student-centered philosophies (Med = 1.5 – 3.0) among those students who discussed the role of the instructor (Table 11). Furthermore, those students who described the importance of the instructor cited that their impactful courses reflected perennialism, an instructor-centered philosophy, more closely than those who did not discuss the role of the instructor ($p \leq 0.01$) (Table 11). Consequently, survey respondents that reflected on an impactful course where the instructor played a key role accurately classified their experience as characteristic of one of the instructor-centered philosophies (essentialism or perennialism).

Table 11. Relationship between role of instructor and enacted philosophy in impactful undergraduate course.

Philosophy	Did Not Discuss Instructor (n = 58)			Discussed Instructor (n = 30)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(1)$	p
Perennialism	4.0	20.6	62.1	4.5	3.3	93.3	8.918	0.003**
Social Recon.	1.0	63.8	24.1	1.5	60.0	20.0	0.028	0.868
Existentialism	2.0	67.3	17.3	2.0	60.0	26.7	2.567	0.109
Progressivism	3.0	31.0	44.8	3.0	13.4	46.6	0.308	0.579
Essentialism	4.0	13.7	68.9	5.0	3.3	83.4	1.966	0.161

Several relationships between the importance of the course subject and the enacted philosophy were identified (Table 12). In general, subject matter was described less frequently for each of the learner-centered courses ($p \leq 0.05$). Perhaps this is because there is more emphasis on the learning *experience*, including development of important skills, rather than the actual *content* in learner-centered environments (Table 2). Conversely, those students who cited the role of the subject matter more frequently classified their impactful courses as characteristic of essentialism, an instructor-centered philosophy ($p \leq 0.05$). Indeed, in an essentialist classroom, there would be emphasis on learning the core content in a discipline (Table 2). Overall, students' descriptions of the role of the subject matter align well with their quantitative assessment of the enacted philosophies in their impactful classrooms.

Table 12. Relationship between role of subject matter and enacted philosophy in impactful undergraduate course.

Philosophy	Did Not Discuss Subject Matter (n = 63)			Discussed Subject Matter (n = 25)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(1)$	p
Perennialism	4	12.6	71.4	4	30.0	76.0	0.044	0.834
Social Recon	2	57.2	25.4	1	76.0	16.0	4.313	0.038*
Existentialism	2	58.7	22.2	1	80.0	16.0	5.269	0.022*
Progressivism	4	22.2	50.8	3	44.0	32.0	4.408	0.036*
Essentialism	4	14.3	68.3	5	0.0	88.0	4.626	0.031*

The impact of course design was cited most frequently for progressivist courses (Table 13). In fact, nearly 60% of students who described aspects of the course design as important (score of 4 – 5) classified their impactful class as progressivist, as compared to only 28% of students who did not discuss course design ($p \leq 0.01$). Indeed, aspects of course design most frequently discussed included particular in-class activities and assessments, such as demonstrations, projects, presentations, labs, competitions, and example problems, many of which are characteristic of a progressivist classroom (Table 2).

Table 13. Relationship between role of course design and enacted philosophy in impactful undergraduate course.

Philosophy	Did Not Discuss Course Design (n = 40)			Discussed Course Design (n = 48)			Kruskal-Wallis Test	
	Median	%1-2	%4-5	Median	%1-2	%4-5	$\chi^2(1)$	p
Perennialism	4	23.1	61.6	4	8.2	81.7	2.812	0.094
Social Recon	2	59.0	25.6	1	65.3	20.4	1.193	0.275
Existentialism	2	66.6	20.5	2	63.2	20.4	0.460	0.497
Progressivism	3	38.4	28.2	4	20.4	59.2	7.630	0.006**
Essentialism	4	10.2	75.9	5	10.2	71.5	0.192	0.661

Disaggregating the data by whether or not respondents discussed student experiences or other stakeholders revealed no statistical differences. Consequently, these aspects were represented among a variety of students' most impactful courses, independent of enacted philosophy.

Limitations

Several limitations are inherent in the design and implementation of this study. Foremost, only graduate students were surveyed about their most impactful undergraduate experiences. Graduate students were likely among the most prepared and successful students in their undergraduate classrooms. Research shows that although active learning is beneficial for a variety of student populations, it may have the most substantial impacts for underprepared and underrepresented students[34,35]. In the context of this study, students tended to find instructor-centered classrooms to be more impactful than learner-centered environments (Table 5). Perhaps this is because as well-prepared undergraduates, participants did not benefit from active learning as much as their less-prepared classmates. Consequently, surveying a more academically-diverse sample may reveal more preference for the learner-centered philosophies.

Other limitations to the sample characteristics are also notable. Most students were male, from the US, and attended research universities as undergraduates. However, even with small sample sizes, students from teaching-focused institutions (Table 7) and international students (Table 6) were found to have unique educational experiences. Surveying a more diverse group of students may have revealed additional and more significant trends in impactful courses.

Finally, the sample size for this study (n = 88) was particularly small. The institution overall is composed of over 3000 graduate students in engineering programs. Consequently, a more representative sample from this institution, as well as multiple institutions, may have provided different results.

Conclusion & Implications

In designing a course to provide significant learning experiences for undergraduate engineering students, we have easily accessible resources in the literature, through our colleagues, and through our own personal experiences. This study captured the voices of the student population, specifically stories of graduate students who are looking back at their undergraduate experience and describing what made a specific undergraduate course particularly impactful. In addition, these results related the characteristics of impactful courses to five diverse educational philosophies and their associated instructional environments. Exploring these impactful classroom experiences highlights connections between the literature and student experiences and supports new engineering educators who are making decisions about the design of their instructional environments.

Implications for Practice

The results of this study aligned with previous work regarding graduate students' educational philosophies[28]. Instructor-centered philosophies dominated, as the most impactful courses reflected either an essentialist or perennialist instructional environment (Table 5). In addition, participants' most impactful experiences were required and/or in-major courses (Table 8). Given that direct instruction predominates in engineering classrooms[36], it is not surprising that students recounted the instructor-centered nature of required and in-major classes. For courses that were not required, the participants identified more breadth in the instructional environments (Table 9). These results suggest students may have different expectations of the learning environment for a required versus non-required course.

Participants appeared to value the connection of course material and assignments to the "real world," whether thronugh linking theory to practice or highlighting "what it's like to be an engineer." These results suggest educators should consider incorporating opportunities for students to explore explicit connections between the theory presented in their courses and the practices of engineers and researchers, as has been suggested by other researchers (e.g., Raju and Sankar[37]). Additionally, participants were impacted in challenging undergraduate courses, specifically those that they later viewed as "doable" or "rewarding." This finding aligns with Lowyck's study[15], discussed earlier, about students' perceptions of high quality learning environments. Thus, as educators, we should explore ways of challenging our students within our courses, while also providing opportunities for our students to feel a sense of accomplishment upon completion of an assignment or the course as a whole.

The literature highlights a connection between students' motivation and their perceptions of the usefulness of the content for their future[38]. Participants in this study appeared to agree with this connection. Many of the courses discussed were viewed as impactful due to the skills the participants developed within the course, the relationship between the course and supporting their career trajectory, and the links between parts of the course and the "real world." Thus, educators can establish learning objectives, assessments, and learning activities that support students' exploration of career possibilities, development of specific skills that are used by professionals in the field, and identification of how this material applies to the world around them.

In addition, participants' discussions emphasized the cognitive higher-order, or the "communication of the material," dimension of instruction[33]. These results suggest that students appreciate instructors who communicate the material in a clear and interesting manner. Additionally, the instructor's interactions with students were also found to be one of the characteristics of an impactful learning environment. Thus, educators can show interest in their students and their students' learning as a way to motivate them throughout the course.

Results from this study suggest that international students may be particularly receptive to learning in the context of grand social challenges (Table 6). Consequently, if a new engineering educator is seeking to connect with a diverse student population, then he or she may illustrate the

relationships between engineering practice and social advancement. Such discussion may also encourage non-international students to use engineering as a mechanism for social change.

Finally, it is important to note that students' perceptions are only one piece of the puzzle involved in course design[9,39]. The development of a powerful learning environment ultimately requires the synthesis of all of the contextual factors (e.g., student characteristics, institutional climate, subject material, instructor characteristics) that could affect the structure and execution of the course.

Implications for Research

The findings presented here suggest additional opportunities for research to investigate students' perceptions of learning environments. Intuitively, the authors expected that capstone design courses would be identified as most impactful. Yet, as can be seen from these results, design courses made up less than 10% of the impactful course experiences (Table 8). Future research could examine *why* capstone design courses were viewed by students as less impactful than non-design courses. Is it because by the time capstone courses come around the student has already had a transformative educational experience, or is it something intrinsic about the way the students were taught in these classes? In addition, international students in this sample reported that their impactful classes were characteristic of social reconstructionism (Table 6). Additional work should seek to target the undergraduate experiences of international students to discover *why* social contexts resonate with them more than students from the US. Is it because some of them come from less-developed countries and have seen first-hand the need to address grand social challenges? More broadly, a similar study using a more diverse cross-section of engineering alumni could provide additional insights about these finding and others. Overall, this study highlighted a need to further explore the undergraduate experiences of graduate students and alumni to identify strategies for designing effective learning environments for a variety of students.

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APPENDIX A.

1. Do you agree for your responses to be used for research purposes? ___ yes ___ no
2. Demographics
   A. Gender:
   B. Citizenship: ___ US Citizen ___ Permanent Resident ___ International (please specify): _____
   C. Undergraduate institution:
      _____
   D. Undergraduate degree(s):
      _____
3. Describe your graduate studies at Georgia Tech.
   A. Home department: [Drop down menu of engineering schools at Georgia Tech – from http://coe.gatech.edu/graduate-academics]
   B. Number of years in graduate school at Georgia Tech: _____
   C. Describe any formal instruction you have received on how to teach a class (check all that apply):

      ___ Tech to Teaching Courses

      ___ GT departmental teaching practicum

      ___ Coursework in teaching/learning from previous institutions

      ___ Other (please specify):

   D. Identify, if any, Tech to Teaching courses you have taken (check all that apply):

___ CETL 8713: Fundamentals of Teaching and Learning *(Previously known as: CETL 8803TL)*

___ CETL 8715: Mentored Practicum *(Previously known as: CETL 8803PR)*

___ CETL 8717: Course Design *(Previously known as: CETL 8803CD)*

___ CETL 8719: Mentored Immersion *(Previously known as: CETL 8801Imm)*

   E. Identify any additional teaching experiences you have had at GT (not including Tech to Teaching experiences) and your previous institutions:

___ Guest Lecturer how many times? _____

___ Teaching Assistant how many times? _____

___ Recitation/Section Instructor how many times? _____

___ Co-Instructor for a course how many times? _____

___ Instructor of Record for a course how many times? _____

___ Other experience (please describe): how many times? _____

4. Reflect on **the course from your undergraduate studies that had the greatest impact on you**.

I. Please provide the name and level (e.g., 1000, 2000, grad-level) of the course and indicate whether the course was part of your major or outside of your major.

_____

II. For each instructional environment, rate the extent to which it is similar to the environment of the course you listed in question I from your undergraduate studies.

Instructional Environment	
Students are encouraged to question facts as they uncover fundamental, unchanging principles and sharpen their analytical skills. Instructors serve as central figures who guide discussions to help students uncover these principles. For instance, emphasis is placed not only on how to manipulate an equation, but also on the reasoning behind the development of the equation.	Not at all similar ____ ____ ____ Very similar
Students learn subject matter as part of thematic units focused on grand social challenges, such as improving access to clean water, developing alternative energy sources, etc. Students and instructors work together to select social themes and decide on learning objectives.	Not at all similar ____ ____ ____ Very similar
Although guided by the instructor, students decide what they learn. Every student is different, so no one set of learning objectives is appropriate for an entire class. The instructor is a facilitator who assists in defining appropriate topics and serves as one of many resources in the learning process.	Not at all similar ____ ____ ____ Very similar
Students participate in hands-on learning as they grapple with real-world questions and problems. Instructors structure learning activities to cultivate student exploration and mold students into life-long learners who can be successful in an ever-changing society.	Not at all similar ____ ____ ____ Very similar
Students learn the existing core of common knowledge in a discipline. Instructors are central figures in the classroom who transfer core knowledge to students in a methodical manner, usually addressing basic concepts before tackling more advanced topics.	Not at all similar ____ ____ ____ Very similar

III. (Optional) What about this course made it so impactful? Please describe briefly in the space below.